

Received: 01 May 2024 • Revised: 20 June 2024 • Accepted: 29 August 2024

Research

doi: 10.22034/jcema.2024.212503

Effect of Using CFRP on the Bearing Capacity of Defected Four-angle Steel Composite Columns

Davood Hosseinabadi *, Kambiz Narmashiri

Department of Civil Engineering, Zahedan Branch, Islamic Azad University, Zahedan, Iran.

*Correspondence should be addressed to Davood Hosseinabadi, Department of Civil Engineering, Zahedan Branch, Islamic Azad University, Zahedan, Iran. Tel: (+98) 9150411456; Email: davoudhossenabadi@gmail.com

ABSTRACT

The main goal of the current research is to study the strengthening of defected four-angle steel composite columns using carbon fiber reinforced polymer (CFRP). Therefore, using numerical studies carried by Abaqus, 19 composite steel column models including 1 specimen without defects, 9 specimens with vertical defects and 9 columns with horizontal defects, with and without the use of CFRP confinement were investigated. Non-linear static analysis was used. After investigating the effect of defect dimensions and the presence of CFRP on the bearing capacity of the studied columns, 5 specimens of numerical models were selected and built for experimental investigation. The uniform compressive axial loading was used. The load was gradually increased. The comparison of numerical and experimental results showed a good agreement. The maximum difference between numerical and experimental results of bearing capacity of the columns is only 0.91%. The Results obtained from this study showed that the presence of defects in the four-angle steel composite column has reduced the bearing capacity of the column. So that, on average, the bearing capacity of specimens with horizontal defects of 15, 30 and 45mm width has been reduced by 0.62%, 1.43% and 8.5%, respectively, compared to the bare model. This decreasing trend regarding the columns with vertical defects by the height of 75, 150, and 225mm is equal to 0.63%, 2.19% and 2.42% respectively. Other results showed that the use of CFRP increases the bearing capacity of the columns. So that the maximum load capacity increase of columns with horizontal and vertical defects due to the use of CFRP is 77.5% (related to H-45-20 model) and 68.2% (related to V-225-5 model) respectively.

Keywords: CFRP; four-angle steel composite columns; defect; Abaqus; experimental investigation

Copyright © 2024, Davood Hosseinabadi. This is an open access paper distributed under the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/). Journal of Civil Engineering and Materials Application is published by (ISNet). Journal p-ISSN 2676-332X; Journal e-ISSN 2588-2880.

1. INTRODUCTION

A column is a member that is usually installed vertically in a building and bears axial force. In a member made of a steel profile (for example, a steel column), buckling is possible in two ways: general buckling of the member and local

buckling (buckling of flange or web of profile section due to compressive stresses). The columns play the most effective role in distributing the axial force transmission from the structure to the substructure. Therefore, damage and destruction of the columns

can lead to progressive failure and collapse of the structure. Four-angle is one of the useful kinds of steel column sections. The metal composite columns consisting of equal flange angle can be classified in the group of square hollow sections (SHS), which are especially used for long columns in steel structures. Reasons such as the loss of column capacity due to corrosion over time, non-compliance with seismic conditions and requirements, increasing the live or dead loads applied to the structure, etc., lead to the strengthening of columns as special load-bearing members of the structure. One of the strengthening techniques of the columns is to strengthen the surrounding environment of compression members by CFRP sheets, which cause confinement pressure in the member and increase its resistance. Therefore, the main goal of this study is to strengthen the defected four-angle steel composite columns by CFRP layers. For this purpose, in this study, first, 19 specimens of short columns were modeled by Abaqus, and then 5 specimens were experimentally tested. Many studies have been conducted on the strengthening of all types of steel, concrete and composite columns by FRP fibers. The first researches in this field were done in the 1990s. In the following, a number of researches conducted in this field have been reviewed. In one of the studies that Dong et al. (2011) conducted on the CFRP strengthening of steel columns filled with concrete, among 22 specimens, they investigated the effect of method of strengthening, type of concrete and shape of the cross-section [1]. They found that CFRP confinement is more effective on solid and hollow circular columns than square sections. Karimian et al. (2020) investigated the CFRP strengthening of defected short circular steel columns [2]. They studied 10 circular defected steel columns with different diameter and heights. The results showed that the defect in the column reduces the bearing capacity, it was also observed that the effect of horizontal defects is more than vertical ones. Furthermore, CFRP showed a good effect on increasing the bearing capacity, reduced stress at the defect location, and prevented the deformation caused by defects. Zhenhai Guo (2011) considered the effect of the initial defect created during the process of making a compression member and basic information about determining the bearing capacity of cold-rolled thin-walled members, using both experimental and numerical methods. The compression members were made of homogeneous

materials in a square shape [3]. Numerical analysis was done by modeling the specimens with initial defects, while the specimens were subjected to the loading process experimentally and were verified the modeling specimens. Damghani and Narmashiri (2020) investigated the CFRP strengthening of defected steel columns filled with mortar [4]. They studied the effect of strengthening of mentioned columns numerically and experimentally. Numerical modeling was carried in 3D using Abaqus and experimental study by uniform pressure device. The results showed that the horizontal defect created in the column has caused the greatest decrease in the bearing capacity compared to the control specimen. Strengthening the defected columns with four layers of carbon fibers in a proper way increased the load bearing capacity by about 27%. The use of carbon fibers in the form of full confinement has significantly helped to increase the confinement resistance and control the local failure of the members. Murilo et al. (2017) conducted an experimental and numerical investigation using the finite element method of perforated tubular (circular) columns under axial compressive load [5]. In their experimental program, 15 pipes columns of different dimensions were tested and their results were compared with the numerical values according to the geometry, the different thickness distribution and the stress-strain diagrams of the specimens. The modeling results showed remarkable accuracy and a good agreement with the experimental results of the force-displacement diagrams in the perforated specimens. The results showed that the dimensions of the holes play an effective role in the amount of compressive strength. Pakrou et al. (2021) investigated the effect of surface preparation of CFRP reinforced concrete beams on their bending capacity [6]. The results obtained from this study showed that the bending capacity of the beams with one and two layers of CFRP reinforcement increased by 45.9% and 64.8% respectively. Hadi et al. (2010) showed that CFRP strengthening can increase the axial force and the plasticity capacity of the members. Furthermore, strengthened circular columns showed better behavior than hollow columns with a square cross-section [7]. Yousefi et al. (2022) investigated the compressive strengthening of circular steel column with local corrosion by CFRP [8]. In fact, 19 circular columns were modeled by Abaqus and 6 specimens were analyzed experimentally. In this research, first, the specimens

were subjected to buckling analysis, and then Reax non-linear analysis method was used to analyze the specimens, taking into account the defect in a general and local way. The results obtained from the study showed that the corroded columns faced with a depression in bearing capacity and stiffness, and the complete destruction of the damaged area reduced the bearing capacity for the column with middle damage and near support damage by 40% and 21% respectively, which indicates that the damage in the middle of the column is more critical. The use of

carbon fibers was able to compensate for the load reduction by 33% and showed a good effect in controlling ruptures and reducing tensions in the damaged area. By reviewing the research literature, it was observed that, despite the considerable number of studies conducted regarding the strengthening of various structural elements, there are less comprehensive and complete numerical and experimental research carried on strengthening of defected four-angle steel composite columns using CFRP.

2. MATERIALS AND METHODS

In this study, 18 specimens of short defected four-angle steel composite columns and one specimen without defects (the bare specimen) were modeled in Abaqus (19 models in total) and then 5 specimens were selected and experimentally subjected to direct axial loading in the structure laboratory of Islamic Azad University of Zahedan. The results of the two methods have been collected and compared in the form of a force-displacement diagram. The bare model named Model-0 is not defected and other models have defects. For models with horizontal and vertical defects, H (Horizontal) and V (Vertical) is assigned respectively in the name of them. After defining the horizontal or vertical nature of the defect, the dimensions of the defect are stated. In this way, the larger dimension of the defect is mentioned first, and then the smaller dimension of the defect is presented in millimeters. For example, a model named V-225-5 is related to a model in which a

vertical defect of 225 mm length and 5 mm width has been created. Also, for loading it was determined by trial and error that a displacement of 1 mm within 1 second is enough to bring the column to the failure area. In addition, a displacement of 0.5 mm is applied to the upper point of the column to create eccentricity from the center and buckling of the column plates. The models also include 1 model without defects, 9 models with horizontal defects and 9 models with vertical defects. The dimensions of the models and their defects are presented in [Figure 1](#). The height of all the columns is considered as 300 mm. Each of the columns consists of 4 angles, the length of the flanges is 30 mm and their thickness is 3 mm. [Table 1](#) introduce the models studied in the current research. It should be noted that in all models, the height and cross-sectional area of the column are constant and the only difference is in the defects created on the outer face of the column.

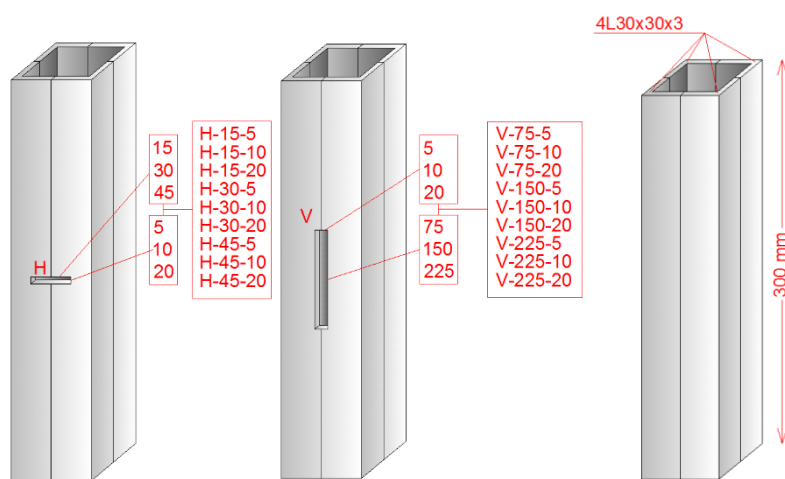


Figure 1. Dimensions and sections of defected and non-defected columns.

Table 1. Columns and defects dimensions.

Name	Horizontal defect (mm)	Defect width (mm)	Vertical defect (mm)	Defect width (mm)
Model-0	0	0	0	0
H-15-5	15	5	0	0
H-15-10	15	10	0	0
H-15-20	15	20	0	0
H-30-5	30	5	0	0
H-30-10	30	10	0	0
H30-20	30	20	0	0
H-45-5	45	5	0	0
H45-10	45	10	0	0
H-45-20	45	20	0	0
V-75-5	0	0	75	5
V-75-10	0	0	75	10
V-75-20	0	0	75	20
V-150-5	0	0	150	5
V-150-10	0	0	150	10
V-150-20	0	0	150	20
V-225-5	0	0	225	5
V-225-10	0	0	225	10
V-225-20	0	0	225	20

2.1. Verification

Here, it is intended to calibrate the finite element model for a steel column strengthened with CFRP according to the experimental study of Bambach et al. (2009) [9]. In the following, the calibrated model will be developed for the defected for-angle short column and the effect of applying CFRP with different conditions on this column will be investigated. In the following, the contours of stress and plasticity of the column are shown with and without CFRP, and also a comparison is made between the load-displacement diagrams obtained from the Bambach experimental research and the current finite element models. Stress contours and plasticity percentage in two states of strengthened and non-strengthened columns are

presented in [Figure 2](#). In this figure, the proper and approximately uniform distribution of stress throughout the column and the prevention of local buckling after CFRP installation are visible. This issue has made all the steel materials to be used in the best way and local damage of the column can be prevented. Therefore, the axial bearing capacity of the column has increased after applying CFRP sheets around the column. [Figure 3](#) shows the load-displacement diagram, in which the maximum deformation of the structure and the maximum bearing capacity of the columns is presented for strengthened and non-strengthened specimens.

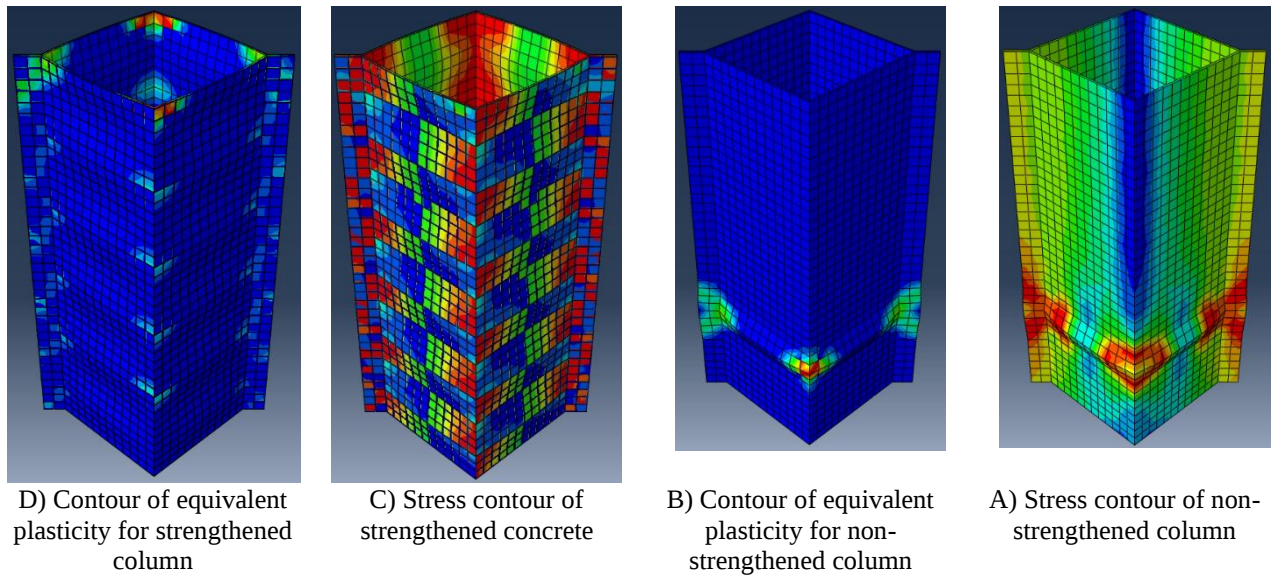


Figure 2. The contours obtained from Abaqus analysis related to the strengthened and non-strengthened models for validation.

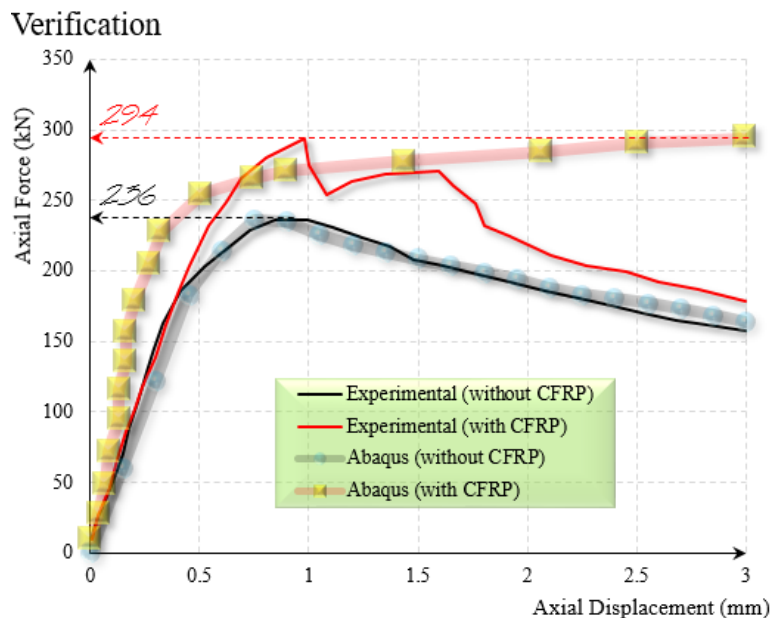


Figure 3. Comparing the results of experimental and numerical analysis of strengthened and non-strengthened columns.

In the experiment conducted by Bambach et al. (2009) the deformation and maximum bearing capacity of the structure were obtained as 3 mm and 236.59kN respectively. After modeling this column by Abaqus, 3mm displacement has been applied to the model and the bearing capacity of the model has been estimated as 235.11kN, which is only 0.6% different from the experimental results. Also, the deformation and

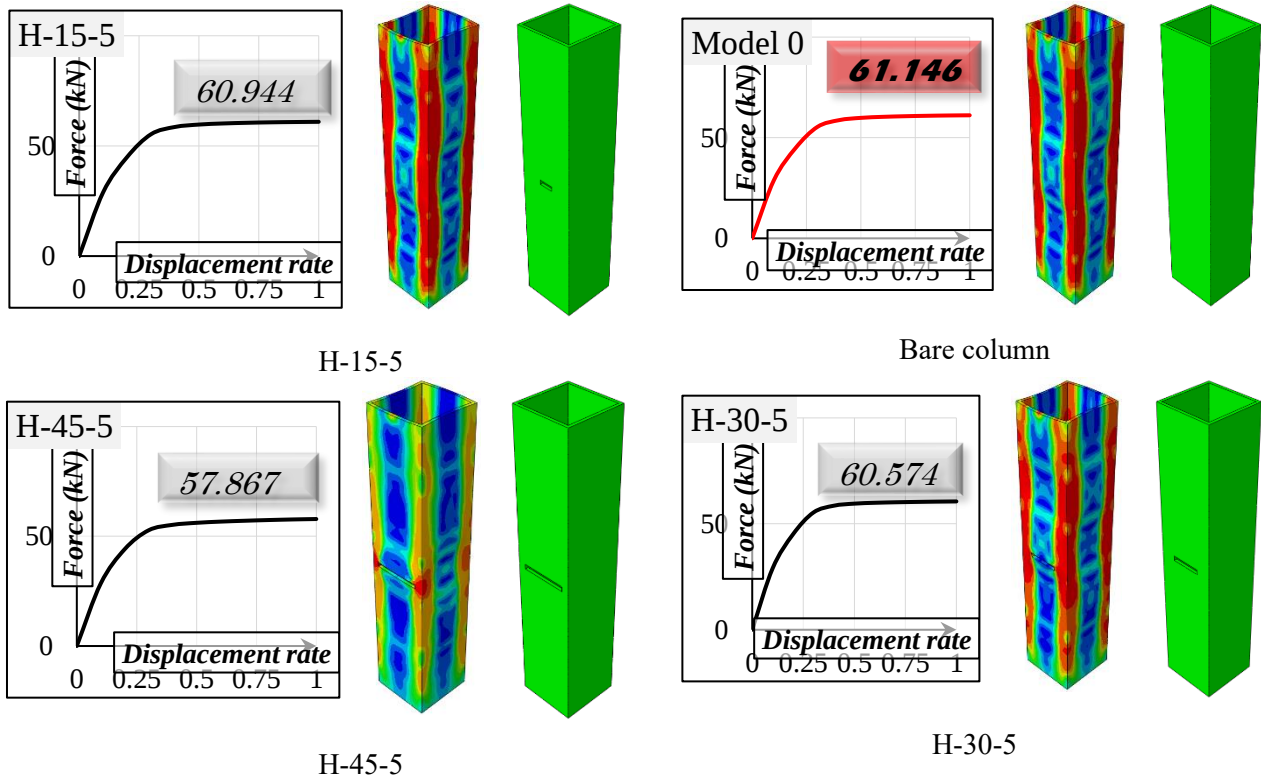
bearing capacity of the experimental analysis were 3mm and 294.25 kN, respectively. The bearing capacity in the numerical analysis by Abaqus was calculated as 296.48 kN, which shows only 0.7% difference. The insignificant difference obtained in the experimental and numerical results shows the accuracy of finite element models provided by Abaqus and the correct calibration of the model.

3. RESULTS AND DISCUSSION

In this section, the simulated model in the software environment, the stress contour and the bearing capacity diagram for the selected models are presented (Figure 4). It should be noted that the horizontal axis in the bearing capacity diagram indicates the applied displacement rate (mm/sec) and the vertical axis indicates the bearing capacity of the columns.

In order to investigate the effect of the dimensions of horizontal and vertical defects on the bearing capacity of the columns, the bearing capacity of 18 defected column models with the bearing capacity of the control model (specimen without defects) has been presented in Figure 5. In this figure, the first thing that is noticeable is reduction of the bearing capacity of all specimens compared to the control model. Table 2 shows the average bearing capacity of defected columns considering different widths and heights of defect. Therefore, it can be concluded that the presence of defects in the four-angle steel

composite columns has reduced the bearing capacity. In fact, on average, the bearing capacity of specimens with horizontal defects of 15, 30 and 45mm width has been reduced by 0.62%, 1.43% and 8.5%, respectively. This decreasing trend for the columns with vertical defect of 75, 150, 225mm is equal to 0.63%, 2.19% and 2.42% respectively. Also, the obtained results show that when the defect is horizontal, the bearing capacity of the column is very sensitive to defect dimensions as it can be clearly seen in the 45mm wide defect (8.5% reduction in carrying capacity). For H-45 models, increasing the height of the defect and changing from 5 mm to 20mm has caused a very severe drop in the model's carrying capacity. The reason for this is the low threshold of column plate buckling in this model, which has reached a critical level. The decrease of bearing capacity in each specimen with vertical defects against the increase in the width of the defect can also be seen in Figure 5.



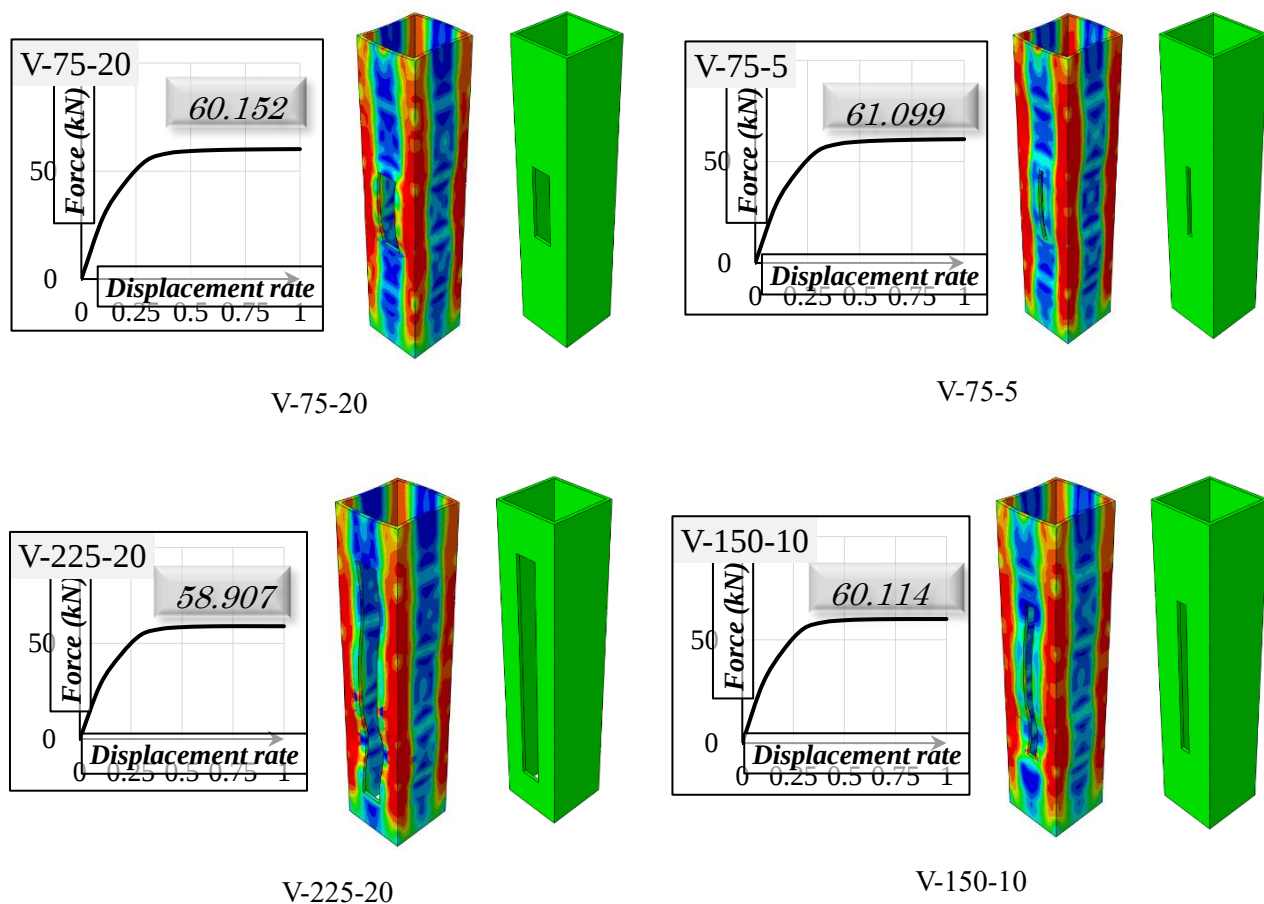


Figure 4. Force-displacement diagrams of bare and defected columns.

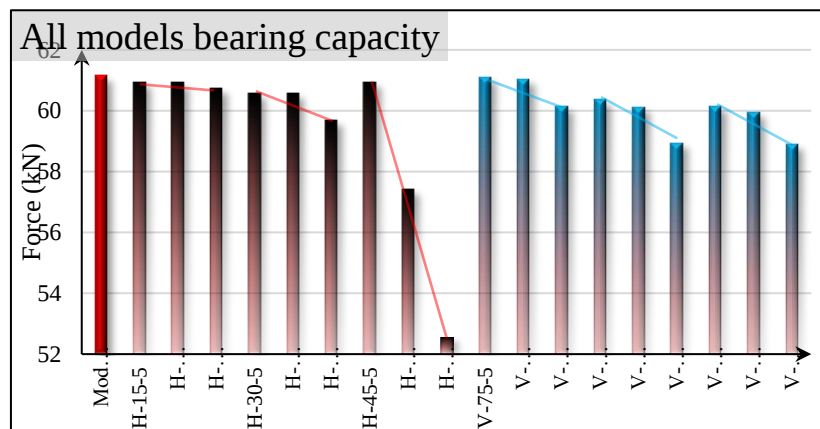


Figure 5. Bearing capacity of all columns.

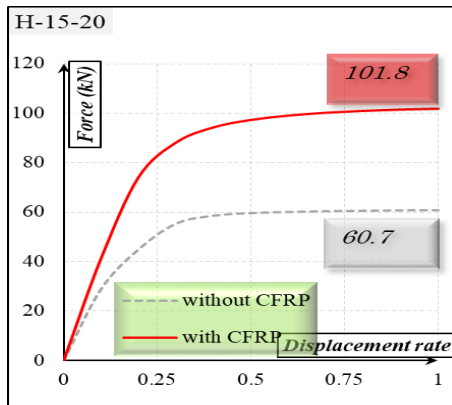
Table 2. Average bearing capacity of columns

Name	Bearing capacity (kN)	Difference with bare (%)
Model-0	61.146	-----
H-15-x	60.767	-0.62
H-30-x	60.272	-1.43
H-45-x	55.950	-8.5
V-75-x	60.758	-0.63
V-150-x	59.806	-2.19
V-225-x	59.668	-2.42

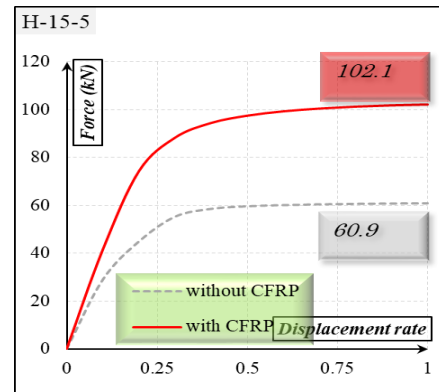
In order to investigate the effect of CFRP on the bearing capacity of the columns, the bearing capacity of 18 column models with horizontal and vertical defects strengthened with CFRP has been investigated. Figure 6 shows the bearing capacity of the CFRP strengthened and non-strengthened columns. It should be noted that the names of the models are the same as before, with the difference that for comparing the models with and without CFRP, they are presented with the expressions with CFRP and without CFRP, respectively.

Based on the obtained results, it is clearly shown that CFRP application has significant effect on the behavior of the discussed columns and increase of their bearing capacity. The maximum bearing capacity values of the models with and without CFRP are presented separately in figure

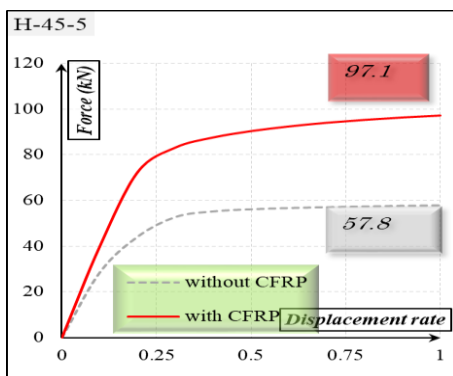
7 for models with horizontal and vertical defects. Figure 7 shows the important effect of CFRP on increasing the bearing capacity of the specimens. The maximum increase in bearing capacity of columns with horizontal and vertical defects due to the use of CFRP is 77.5% (related to H-45-20 model) and 68.2% (related to V-225-5 model) respectively. But in order to obtain the most sensitive models due to the use of CFRP, the rate of change of the bearing capacity of the specimens before and after the application of CFRP is shown in figure 8. It is observed that H-45-20 has the highest sensitivity and the highest change rate with horizontal defects compared to the control model (rate 0.0525). It can also be seen in the models with vertical defects that V-225-20 has the highest change rate and the highest sensitivity (rate 0.0168).



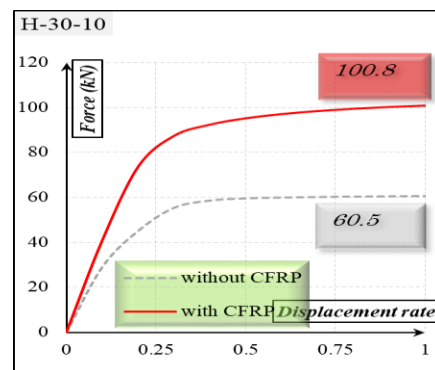
H-15-20 model with and without CFRP



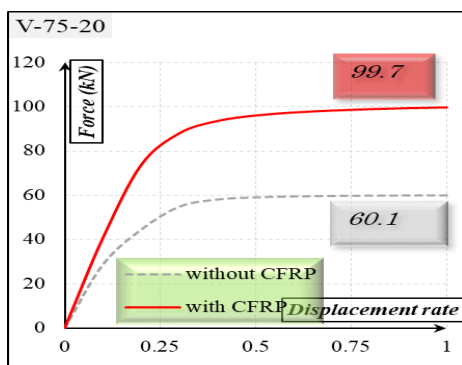
H-15-5 model with and without CFRP



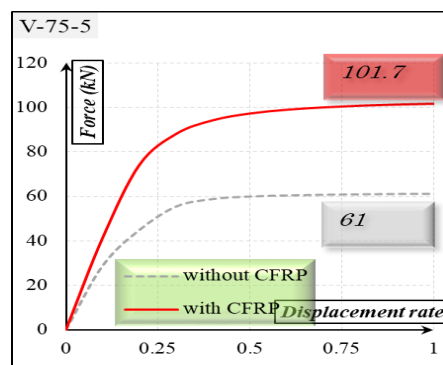
H-45-5 model with and without CFRP



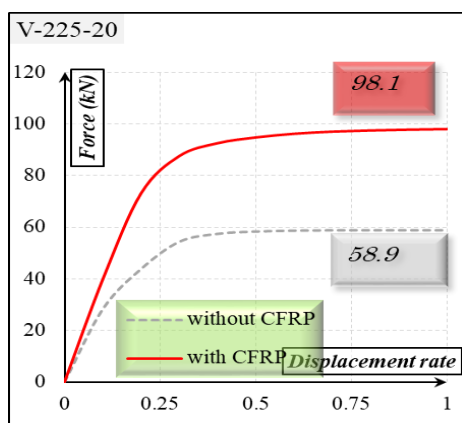
H-30-10 model with and without CFRP



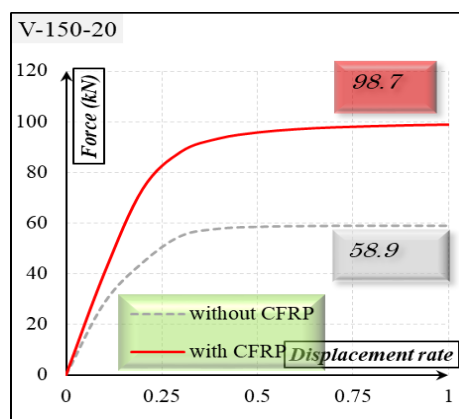
V-75-20 model with and without CFRP



V-75-5 model with and without CFRP

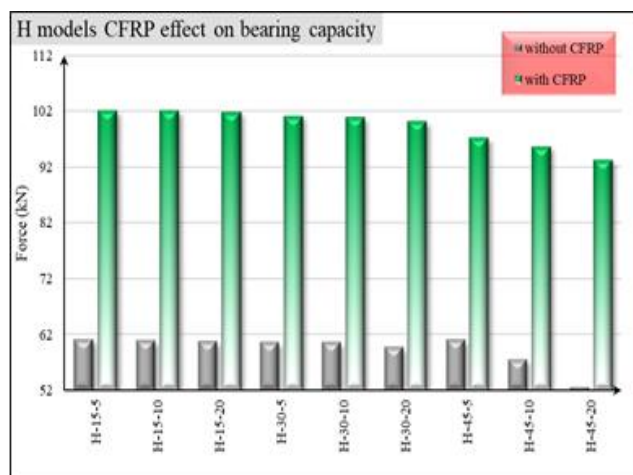


V-225-20 model with and without CFRP

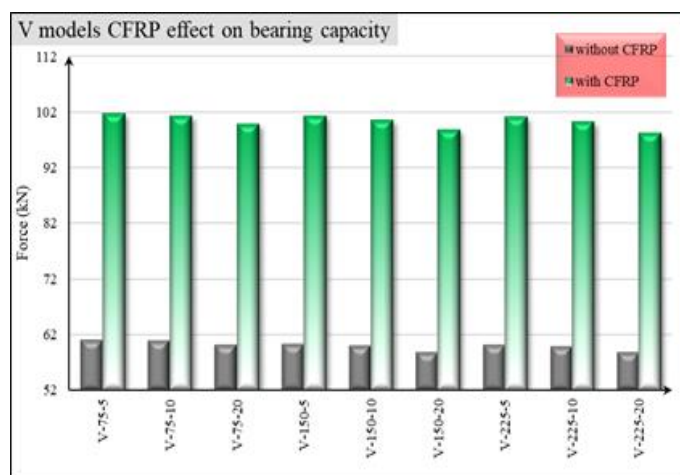


V-150-20 model with and without CFRP

Figure 6. Force-displacement curve of selected models with and without CFRP strengthening.



Horizontal defected columns with and without CFRP



Vertical defected columns with and without CFRP

Figure 7. Bearing capacity of all horizontal and vertical defected columns with and without CFRP.

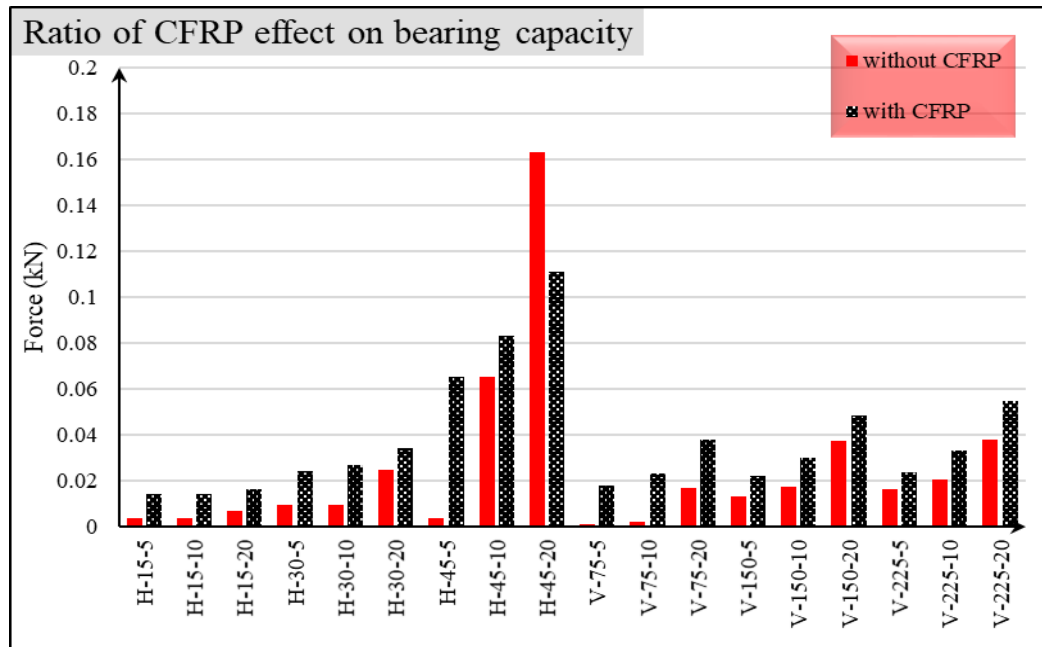


Figure 8. The rate of change of bearing capacity of the columns.

In order to investigate the experimental strengthening of the studied columns in the present study and considering the large number of studied specimens, 5 column models were selected and made in the laboratory environment. The criterion for choosing experimental columns was the sensitivity parameter of the models. Therefore, H-45-20 (among horizontal defected columns) and V-225-20 (among vertical defected columns) with and without CFRP in addition to control (bare) model were selected as 5 experimental specimens. Experimental bearing capacity of specimens are shown in Table 3. As it can be seen, the bearing capacity of bare, V-225-20, V225-20-CFRP, H-45-20 and H-45-20-CFRP are 61.7, 59.1, 98.3, 52.7 and 93.5kN respectively. The obtained results indicate the conformity of numerical and experimental values, so that the maximum difference of the bearing capacity of the columns modeled by software and experimentally made ones is only 0.91%. Figure 9 shows the effect of defect dimensions and CFRP on bearing capacity of

columns for numerical and experimental specimens. It can be observed that the defect can reduce the bearing capacity of the columns. In fact, the bearing capacity of V-225-20, compared to the bare model in numerical and experimental study has decreased by 3.67% and 4.2% respectively. Also, the bearing capacity of H-45-20, compared to the bare model in numerical and experimental study has decreased by 14.1% and 14.6% respectively. It can also be observed that by using CFRP in defected columns, the bearing capacity of columns has been increased. In fact, the bearing capacity of V-225-20-CFRP, compared to the bare model in numerical and experimental study has increased by 60.43% and 59.3% respectively. Also, the bearing capacity of H-45-20-CFRP, compared to the bare model in numerical and experimental study has increased by 52.4% and 51.5% respectively. It should be noted that the obtained results confirm the acceptable conformity of numerical and experimental investigations carried in the current study. Figure 10 shows the selected images of the experimental specimens.

Table 3. Bearing capacity of experimental columns.

Name	Bearing capacity (numerical)	Bearing capacity (experimental)	Difference with bare
Model-0	61.146	61.7	0.91%
H-45-20	52.5	52.7	0.38%
H-45-20-CFRP	93.2	93.5	0.32%
V-225-20	58.9	59.1	0.34%
V-225-20-CFRP	98.1	98.3	0.2%

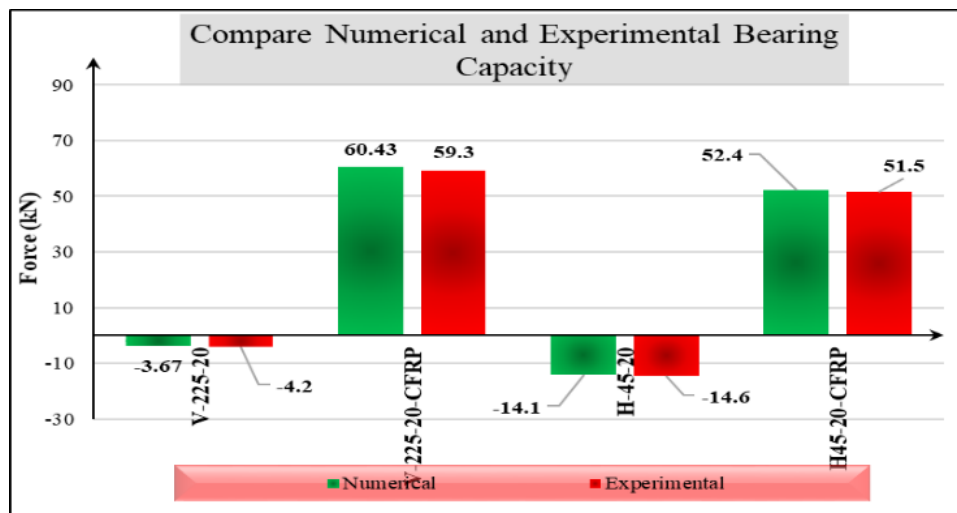


Figure 9. Comparing the bearing capacity of numerical and experimental models.



Figure 10. Selected images of experimental specimens.

4. CONCLUSION

Based on the analysis carried in this research, the results can be summarized as follows:

- Defects in the four-angle steel composite column have reduced the bearing capacity of the column. In fact, on average, the bearing capacity of specimens with horizontal defects of 15, 30 and 45mm width has been reduced by 0.62%, 1.43% and 8.5%, respectively, compared to the bare model. This decreasing trend regarding the specimens with vertical defects of 75, 150, and 225mm height is equal to 0.63%, 2.19% and 2.42% respectively.
- In models with horizontal defects, the bearing capacity is more sensitive to the dimensions of the defect. This issue can be clearly seen in the 45mm wide defect (8.5% reduction in bearing capacity). In H-45 models, increasing the height of the defect from 5 mm to 20 mm has caused a very severe drop in the bearing capacity.
- The obtained results show that the use of CFRP increases the bearing capacity of the defected columns. So that the maximum load capacity increase of columns with horizontal and vertical defects due to the use of CFRP is 77.5% (related to H-45-20 model) and 68.2% (related to V-225-5 model) respectively.
- It is observed that H-45-20 model has the highest sensitivity and the maximum change

rate among the models with horizontal defects compared to the bare model (rate 0.0525). Also, between vertically defected models, V-225-20 has the highest change rate and the maximum sensitivity (rate 0.0168).

- The results obtained from numerical modelling and experimental are sufficiently confirmed. So that the maximum difference obtained in the bearing capacity of the columns modeled by the software and the columns made experimentally is only 0.91% different.
- The results obtained from the experimental studies also show that the presence of defects has reduced the bearing capacity of the column, so that the bearing capacity of V-225-20 model in numerical and experimental investigations has been decreased by 3.67% and 4.2% respectively. These values for H-45-20 are 14.1% and 14.6% respectively.
- Other results obtained from experimental studies show that by using CFRP in defected columns, the bearing capacity will be increased. So that the bearing capacity of V-225-20-CFRP model in numerical and experimental investigations has increased by 60.43% and 59.3%, respectively. These values for H-45-20-CFRP are 52.4% and 51.5%, respectively.

FUNDING/SUPPORT	AUTHORS CONTRIBUTION
Not mentioned any Funding/Support by authors.	This work was carried out in collaboration among all authors.
ACKNOWLEDGMENT	CONFLICT OF INTEREST
Not mentioned by authors.	The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

5. REFERENCES

[1] He, Dong et al. "Mechanical behaviour of recycled concrete filled steel tube columns strengthened by CFRP." 2011 International Conference on Multimedia Technology (2011): 1110-1113. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[2] Karimian M, Narmashiri K, Shahraki M. Strengthening of deficient short circular-shaped steel columns Using CFRP. Journal of Current Research in Science. 2016 Jan 1(1):596. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[3] Guo Z, Shi X. Experiment and calculation of reinforced concrete at elevated temperatures. Elsevier; 2011 Jun 15. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[4] Badih Damghani I, Narmashiri K. Strengthening of Deficient Mortar Filled Steel Columns using CFRP. Amirkabir Journal of Civil Engineering. 2020 Apr 20;52(2):513-28. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[5] Vaz MA, Cyrino JC, Hernández ID, Zegarra VD, Martinez JL, Liang DA. Experimental and numerical analyses of the ultimate compressive strength of perforated offshore tubular members. Marine Structures. 2018 Mar 1;58:1-7. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[6] Pakroo M, Ameri KB, VARASTEHPOR H. The effect of preparing of reinforced concrete beams with CFRP on their flexural strength. 2021, (14), (2), P107-117. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[7] Kusumawardaningsih Y, Hadi MN. Comparative behaviour of hollow columns confined with FRP composites. Composite

Structures. 2010 Dec 1;93(1):198-205. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[8] Yousefi O, Hedayat AA, Narmashiri K, Karbakhsh A. Compressive strengthening of steel columns with local corrosion using CFRP. Amirkabir Journal of Civil Engineering. 2022 Jul 23;54(5):1835-56. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[9] Bambach MR, Jama HH, Elchalakani M. Axial capacity and design of thin-walled steel SHS strengthened with CFRP. Thin-Walled Structures. 2009 Oct 1;47(10):1112-21. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).